Würzburg Radiotelescope
Description and User Manual

Fabrice Herpin/David Smith
wurzburg@obs.u-bordeaux1.fr
Version 2.1

Longitude 0°31’32” O, Latitude 44°50’6” N, Altitude 73m

Summary

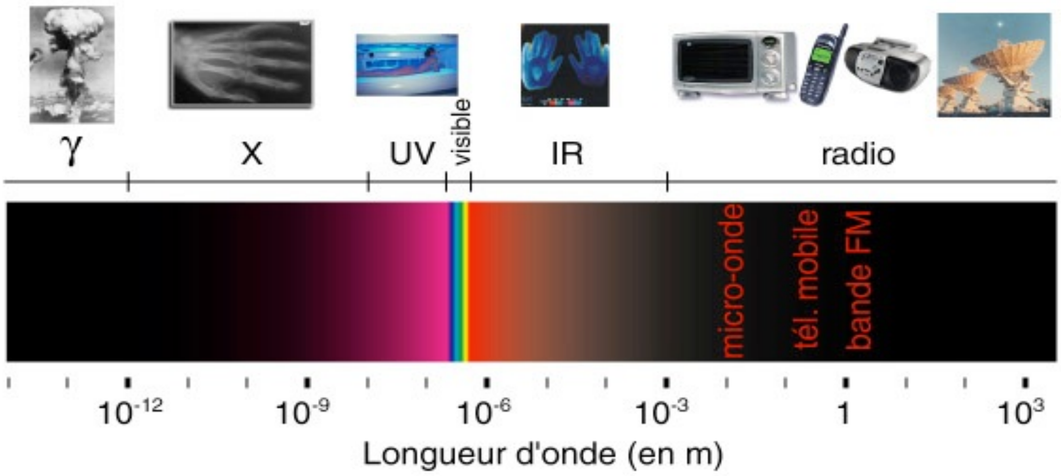
In the Fall of 2007, at the LAB/OASU in Floirac, near Bordeaux, we began the renovation of a Würzburg radio telescope, to convert it into a powerful tool for teaching and outreach. Teachers (all levels of education), students, and amateur astronomers can now use it to study galactic HI and OH emission. One can use it via a web interface or locally, individually or through mini-courses on-site supervised by the research staff. This tool is now part of the "Hands-On Universe" project. Note especially that the telescope is open to all, for free!

This manual covers the version 2 interface.

Table of Contents

I. *INTRODUCTION TO RADIO ASTRONOMY*

Less known to the general public than optical astronomy, radio astronomy has made many major discoveries since the middle of the 20th century. Examples are the discovery of the cosmic background radiation, quasars, and pulsars. The advantage of using radio telescopes is the possibility of observations in daylight, from the city, of objects in our Galaxy and far beyond.



Radio astronomy is the science that studies the electromagnetic radiation from astronomical sources emitted at frequencies from a few MHz to 2 THz (or wavelengths λ of a few tens of meters to a few tenths of a millimeter). Radio wavelengths are longer than optical wavelengths. The millimeter (λ> 1 mm) and submillimeter (λ <1 mm) domains allow the exploration of regions inaccessible at optical and UV wavelengths: for example, young star-forming regions. These areas are relatively cold, and emit mainly radio frequencies.

The signals picked up by radio telescopes are electromagnetic waves emitted by molecules, atoms or ions in space, around stars, in molecular clouds, etc. These species have been excited by a heating source (e.g. star or gas shocks), then emit photons by relaxing to their normal state. The emission of each molecule is very weak, but given the vastness of interstellar space, the total emission is perfectly detectable. The signal emission occurs only at very specific and known frequencies. In the same way that turning the knob of a classical radio receiver selects your favorite music channel, the radio telescope is tuned to the frequencies emitted by the molecules, which facilitates their identification.

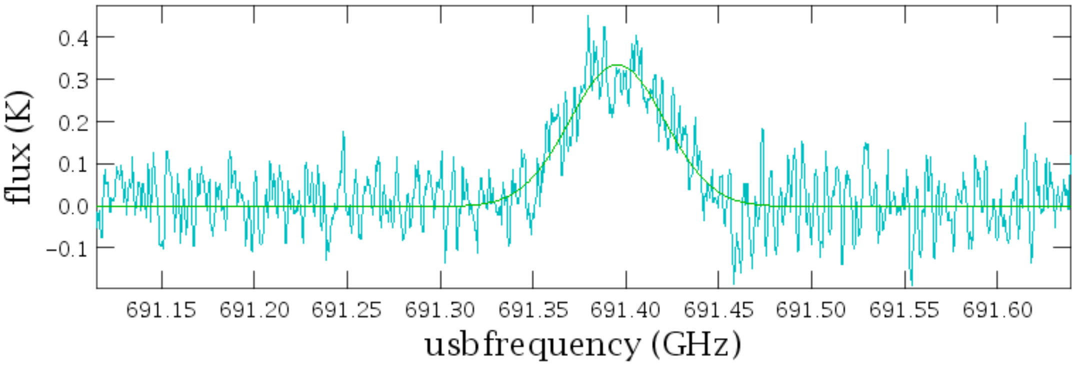


Figure 1: Example of CO molecule radio signal (detected with an antenna other than the Würzburg). The signal is observed over a given frequency and the strength is measured by a quantity called the flux or intensity (in Kelvins).

II. *PRESENTATION OF THE RADIOTELESCOPE*

The Würzburg radiotelescope is a former German army radar, moved to the observatory in 1962. It was used to observe the Sun continuously from 1966 to 1987. Its renovation began in 2007.

Figure 2 : Würzburg radiotelescope (left) and horn (right)

To observe solar bursts, the receiver was set to 930 MHz. Since renovation, the bands of observing frequencies are now between **1.35 GHz and 2.7 GHz**.

The Wurzburg consists of:

- a 7.5 meter diameter collecting parabolic antenna,
- a horn (Figure 2) that receives the signal focussed on it by the antenna and transmits the radio signal to the electronics,
- an electronics systems, with a computer to process the signal and to steer the antenna.

Diffraction limits a telescope to a minimum angular size θ of an object that can be resolved,

$$\theta = 1{,}22\ \lambda/D$$

where:

- λ is the wavelength used for observations,
- D is the antenna diameter.
- θ is taken as the width of the main beam at mid-height, θ = HPBW. That is, a point-like source at infinity will have half the signal intensity when viewed θ radians away from the source direction. (This description of the blurred image is called the approximation of a Gaussian beam.) Determined experimentally, **the antenna beam is θ = 2.8 °**. For its focal length, this means that the horn only 'sees' an antenna diameter of 4.9 m.

III. *WHAT CAN WE OBSERVE WITH THIS ANTENNA?*

The range of frequencies available allows observations of:

- the galactic HI hydrogen H_I in emission/absorption at a wavelength of 21 cm, i.e. at a frequency of 1420.4 MHz,
- the OH maser emissions at 1.6-1.7GHz (see below). The ***OH frequencies are being tested and will be available shortly.***

Why these HI and OH transitions?

Most of the gas in our Galaxy is in hydrogen HI atomic form, which emits radiation at a radio wavelength of 21 cm (that is to say a frequency of 1420 MHz). The 21 cm line was theoretically predicted in 1945 by van de Hulst and has been observed for the first time in 1951.

Most of the stars and gas in our Galaxy is located in a thin disk. The sun is located at a distance of about 8.5 kpc (25.000 light years) from the galactic center. Because of our position in the Galaxy, it is quite difficult to study the three-dimensional structure thereof. Radio astronomy observations of the hydrogen atom helped to reveal the properties of the Galaxy, mainly because this type of radiation is not "quenched" by the dust and the gas expands, unlike stars, beyond the galactic disk.

Our Galaxie

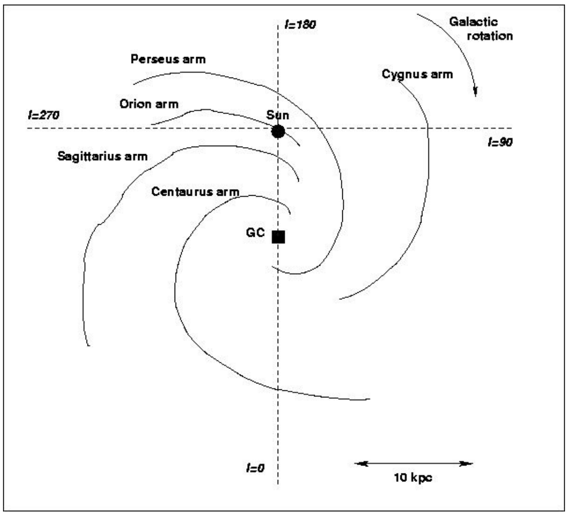


Figure 3 : View of our Galaxy (picture : Onsala observatory, Sweden). «GC» stands for the Galactic center. The position of the Earth coincides with that of the Sun.

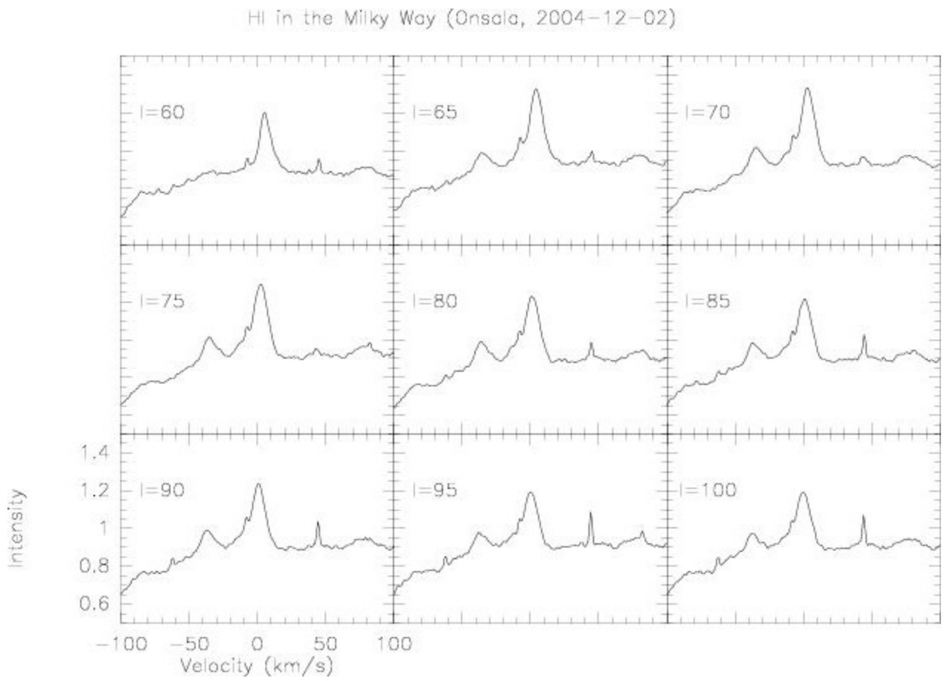
In the galactic coordinates system (see Section VI), the longitude l is counted from zero (the sun to the galactic center axis) and increases counterclockwise. Latitude b gives the angle relative to the plane of the Galaxy (so b = 0 being the galactic plane). On a given position on the Earth, only part of the Milky Way can be observed.

The HI emission

The figure below shows a series of HI spectra of our Galaxy obtained at different longitudes by the Onsala telescope SALSA (roughly equivalent to our instrument).

If the gas has a velocity v relative to the observer, then the wavelength λ of the observed signal changes from a factor $\Delta\lambda = v/\lambda\ c$ where c is the speed of light. This phenomenon is

called "Doppler effect" and $\Delta\lambda$ is the "Doppler shift".
Thus, from the measured frequency for each peak of the HI signal can be inferred the gas velocities: for each spectrum, the peak position of the observed line gives a frequency which, thanks to the Doppler effect, can be converted into speed on the line of sight.
Assuming that the total velocity is constant with the radius (= differential rotation, characteristic of spirals), the distance of the gas cloud can be calculated. This is detailed in Section VI.



The OH emission
OH was the first astronomical molecule detected (1963) in the radio part of the electromagnetic spectrum. The spectral lines of OH are at wavelengths 2.2, 3.7, 5.0, 6.3 and

Notation	Frequency (MHz)
OH(1-2)	1612,2
OH(1-1)	1665,4
OH(2-2)	1667,4
OH(2-1)	1720,5

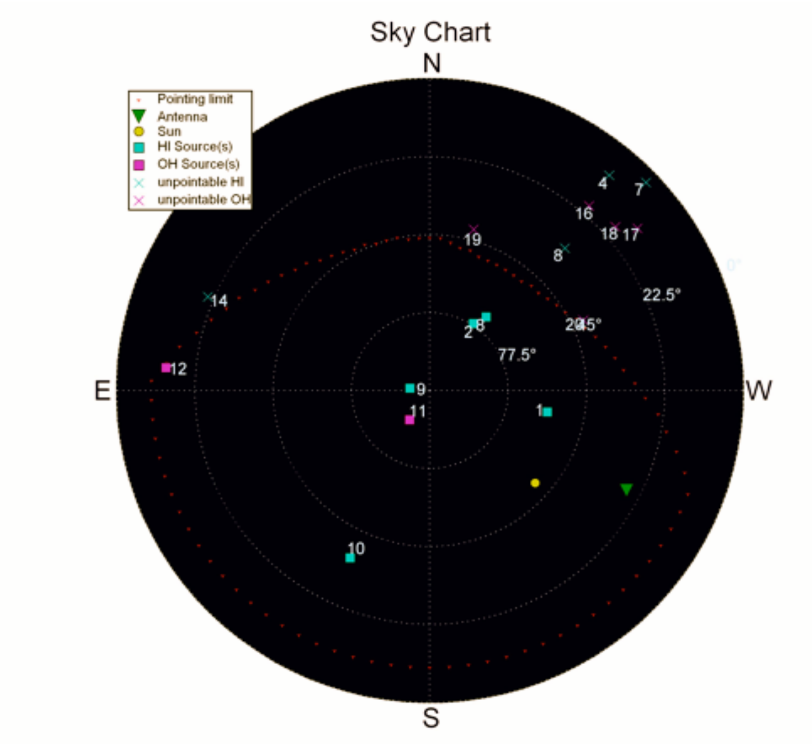
18 cm. This molecule is observed in the Earth's atmosphere, planetary atmospheres, in comets, in molecular clouds, galaxies, but especially in evolved stars (stars older than our Sun with equivalent mass) as maser radiation. OH Maser radiation at 18 cm emitted by evolved stars is actually composed of three lines: the main ones at 1665 and 1667 MHz lines and a satellite line at 1612 MHz.
Depending on the intensity of the OH maser lines at 1.7 GHz, evolved stars can be classified

into different groups (Type I or II). One can also study the frequency of the radiation relative to the change in brightness of the star (the light curve of most of these stars is known). The "classic" OH maser emission spectrum is characterized by a double-peak profile. From the separation in velocity of the 2 peaks, one can infer the expansion velocity of the OH envelope, while the middle velocity gives the velocity of the central star.

IV. *CONSTRAINTS OF THE RADIOTELESCOPE*

1. Instrument field of view

Because of his mount, the antenna can only observe part of the sky (basically anything that is too far north is unobservable). Whenever you select a source to observe, a chart is displayed on the screen with the observable part of the sky. On the image below, the portion of the sky available is bounded by the dotted red (below). When selecting a source outside the field of view of the telescope, a message will warn you.



2. Observing mode

There are several observing modes for a telescope. The one used with the Würzburg is the ***frequency switch*** mode.

This mode consists in observing (integrating) a source for some time at the requested frequency, then in observing the same source (same spatial position) but at a frequency where the source does not emit (off frequency). To obtain the spectrum of the source without the defects inherent to the antenna and the environment, we then just make the difference between the two observations.

The Würzburg provides spectra whose ***bandwidth is 10 MHz with a resolution of 5 kHz***.

3. Integration time

The more we integrate on a source, the better the signal-to-noise ratio and the easier it is to detect faint sources. The electronics of the antenna allows, for the moment, to integrate a maximum of one second in order to ensure system stability. Thus, if you enter as integration

time 100 seconds, the observations will therefore consist of 100 spectra (of 1 each) that you will add later (with a software such as *Class*[1], see section VII).

4. Interferences and off frequency

Cities represent a major source of pollution for astronomical observation. Hence, in the visible range, the observation is made difficult because of light pollution. The presence of interferences in the radio domain is less known (not visible and having less impact on the environment) but also disturbing for astrophysics. While some bands are legally reserved for radio astronomy, it is common to find parasites in these bands due to non-compliance or improper adjustment facilities (presence of harmonics of a signal in reserved bands).

The tests showed that for HI the area around El = 20 ° and Az = 240 ° is very noisy. More generally, any observation below El = 20 ° should be avoided.

Regarding OH, the (2-1) transition is not observable.

In addition, these tests were used to determine the *off* frequency used in the observation *frequency switch* mode. Indeed, as the spectrum is subtracted *off* from the raw spectrum, it has to be free of emission lines (parasite or astronomical source).

5. Reference sources

To validate the calibration of the observations, we observed reference sources whose spectrum is known and present in the Leiden/Argentine/Bonn Galactic HI Survey database (http://www.astro.uni-bonn.de/hisurvey/profile/).

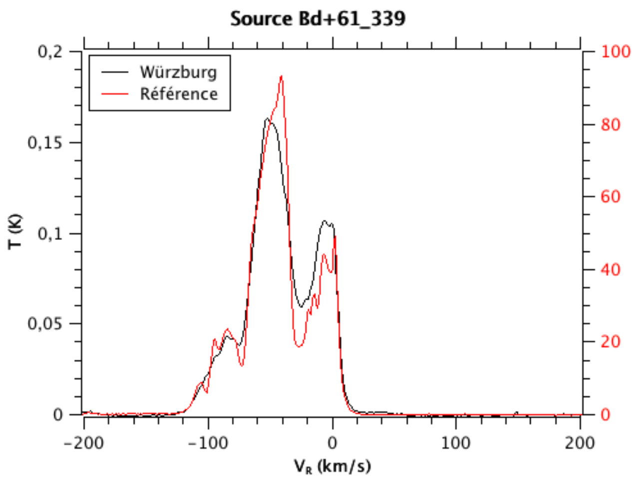


Figure 4 : Comparison between Würzburg spectrum (black) and reference spectrum (red) for an observation of a region of our Galaxy. The details of the spectrum are the same, the velocity and intensity scales too.

[1] CLASS software is developped by IRAM (http://www.iram.fr/IRAMFR/GILDAS)

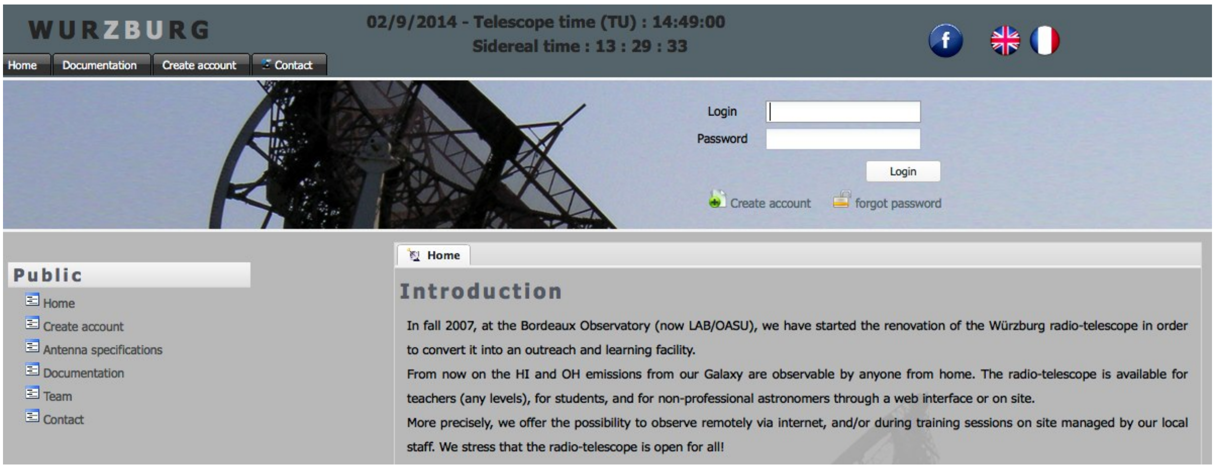
V. HOW TO USE THE RADIO TELESCOPE?

1. Logging on

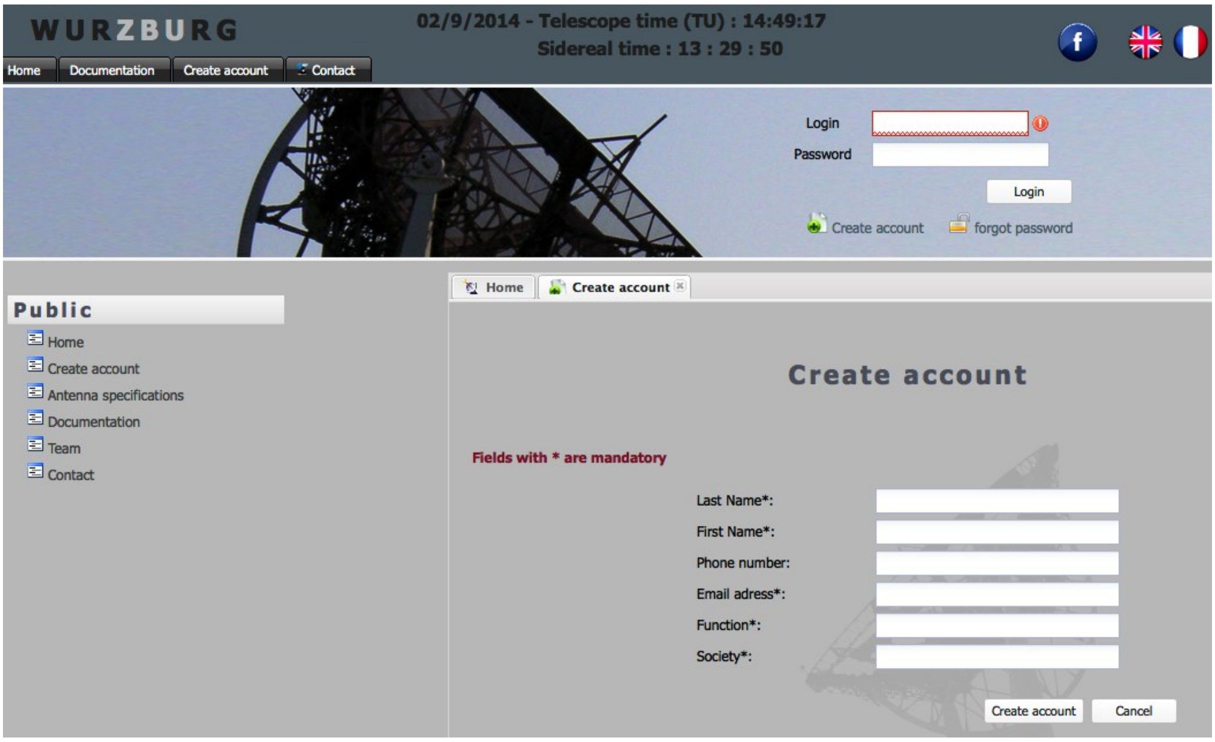
Use any internet brower to access the **Würzburg web page**, shown below.

http://serveurwurzburg.obs.u-bordeaux1.fr

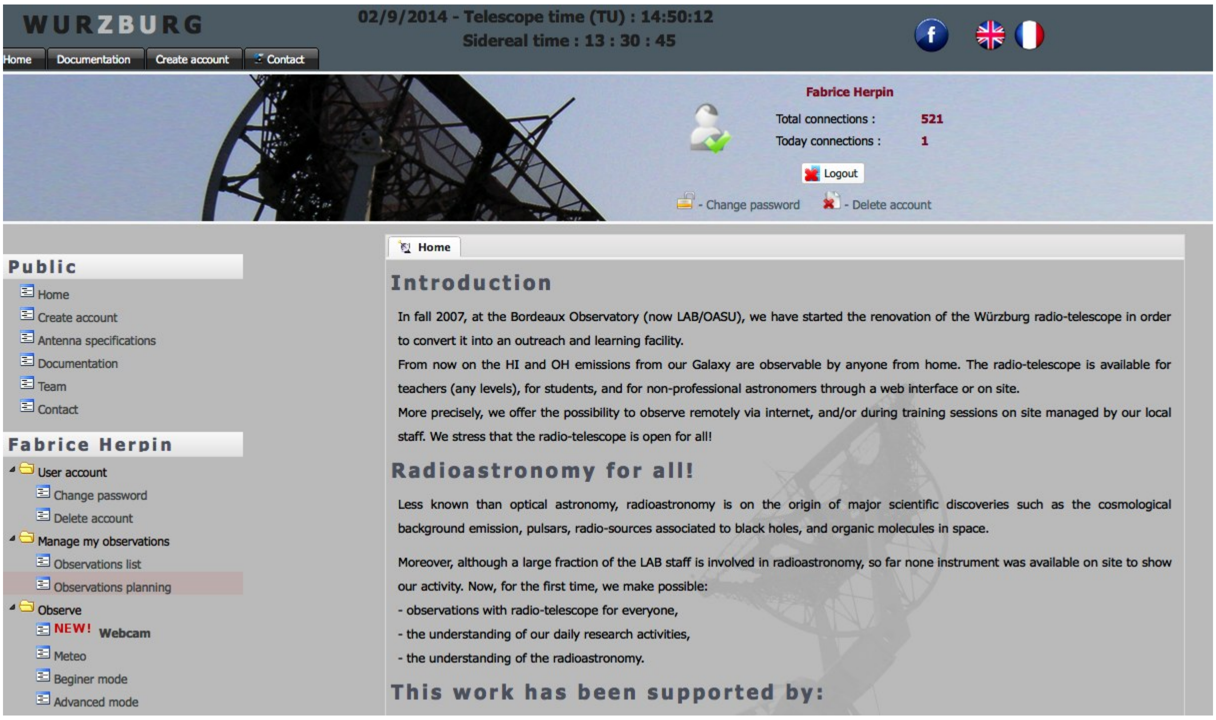
(Firefox and Google Chrome are preferable, however Mac vs PC vs Linux makes no difference.)



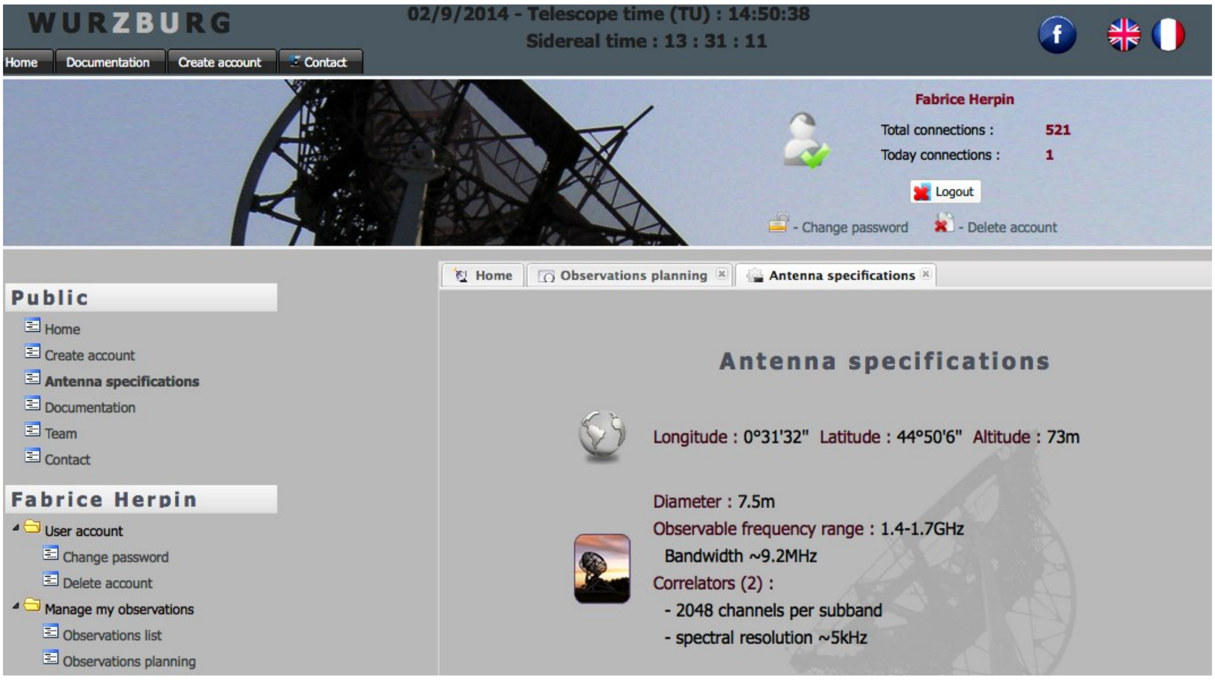
If you are already signed up, log in using your username and password, and go to Step 2.
For new users: click on "Create an account". Fill in the sign-up form, shown in the figure, and click on "sign up!".



Within a few minutes you will receive automatic e-mail with your password. **Note that you must then validate your account by logging in, as per the instructions in the e-mail message.**
Anyone can use the radio telescope – no restrictions apply. We ask for your e-mail address only in case there is some problem, and thus **a valid e-mail address is required.** You can change your password at any time.



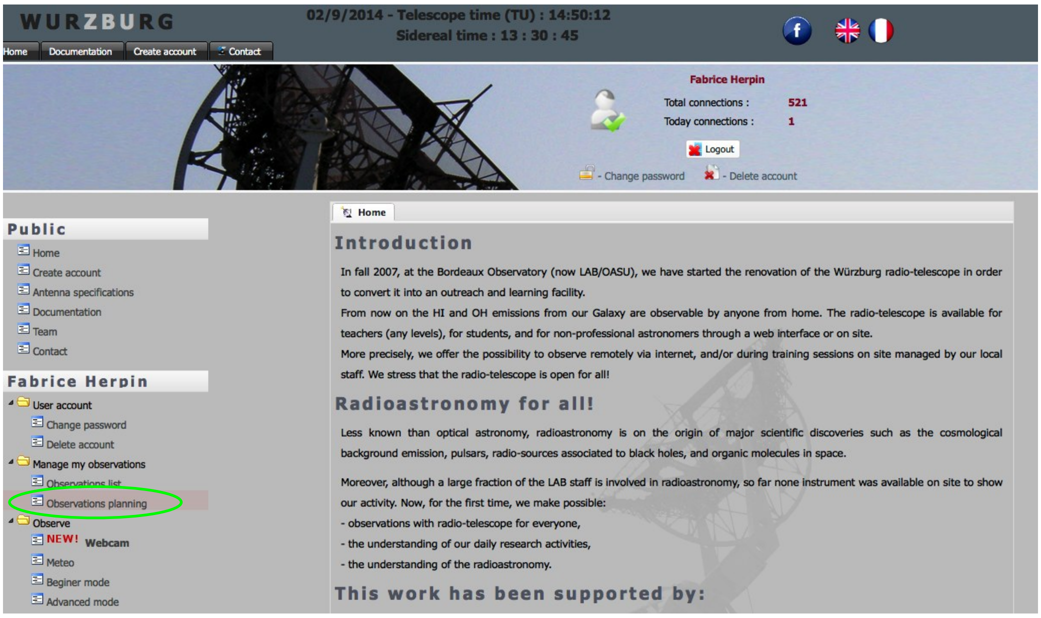
Having created your account, you can log in. The following page appears:



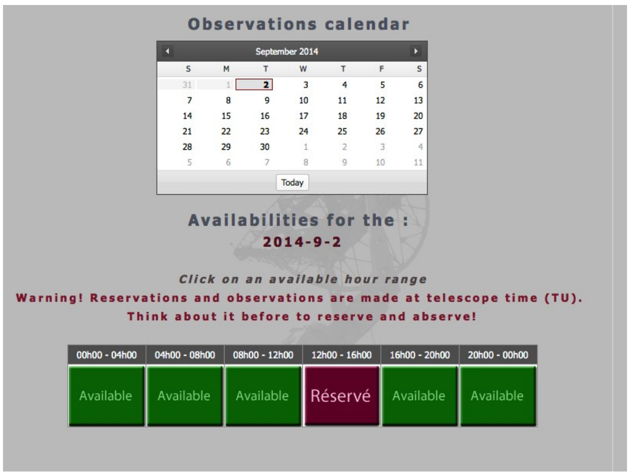
Note that the column of tabs on the left is accessible even without an account. They allow potential users to contact us, to consult the antenna characteristics, and so forth.

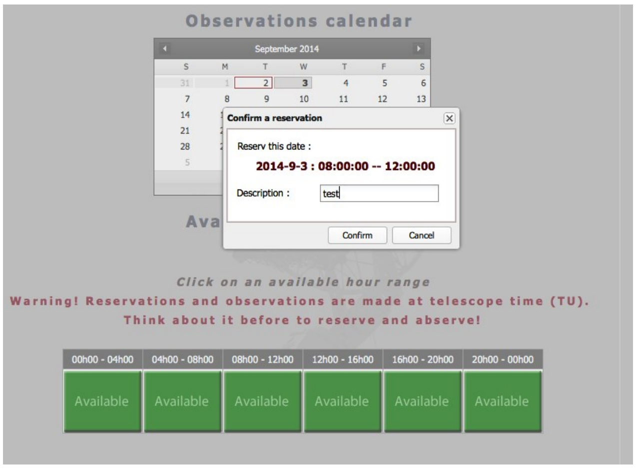
2. Reserving an Observation Session

Once logged in, the "*Manage my observations*" tab gives you access to '**Reserve an observation**' as well as the **list of your reservations and past observations**.



To make an observation, click on the "Observations calendar" tab. The following page appears:

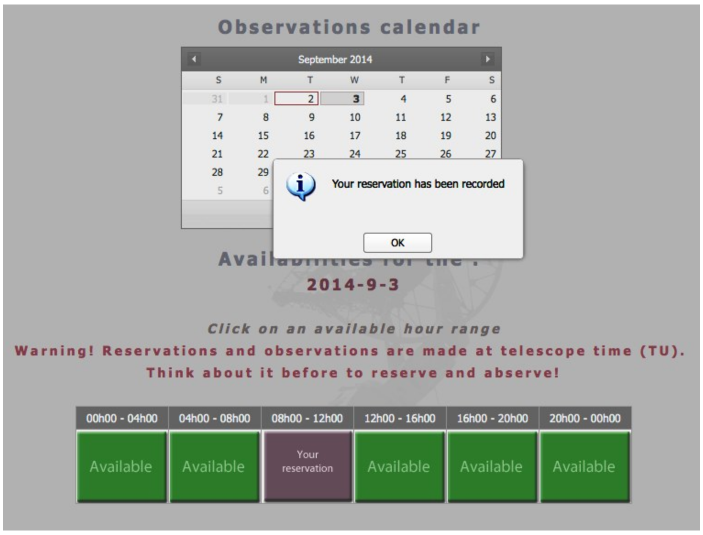




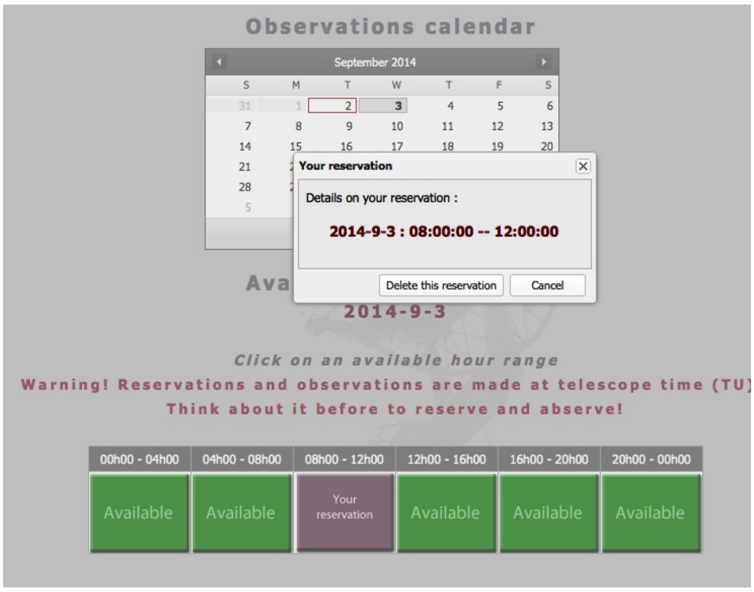
To reserve, simply click on a date. The different time slots then appear, green indicating which are free. You can reserve as many as you like. ***Note that the reservation times are un UT = Universal Time.***

You then enter a few words to describe your observation's purpose (examples: '*1st try for a beginner*', '*Elucidate the secrets of the Universe*', '*There's nothing good on TV*', etc.).

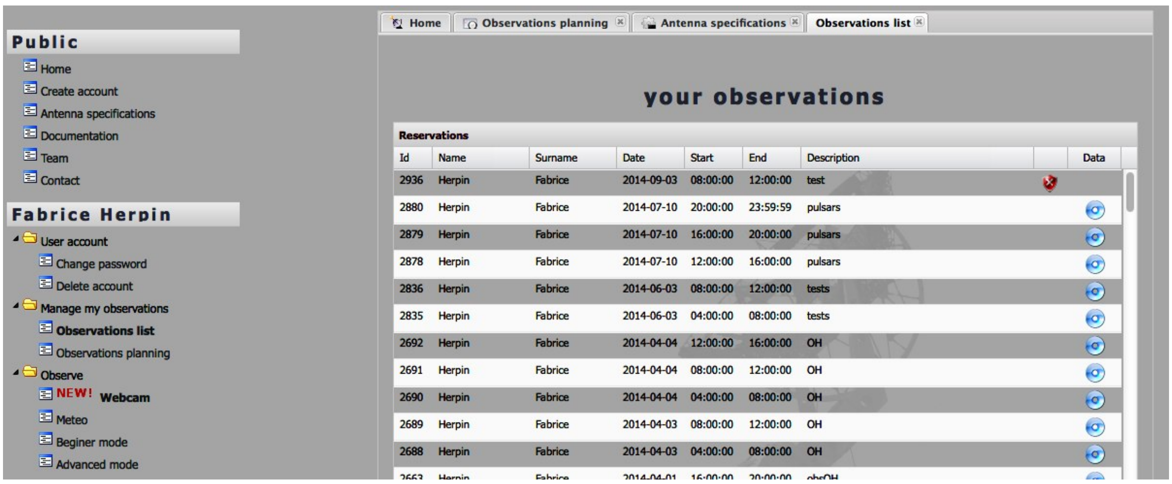
Your reservation then appears on the calendar ('Your reservation') as well as on the Observations list.



To cancel your reservation at any time, click on it.

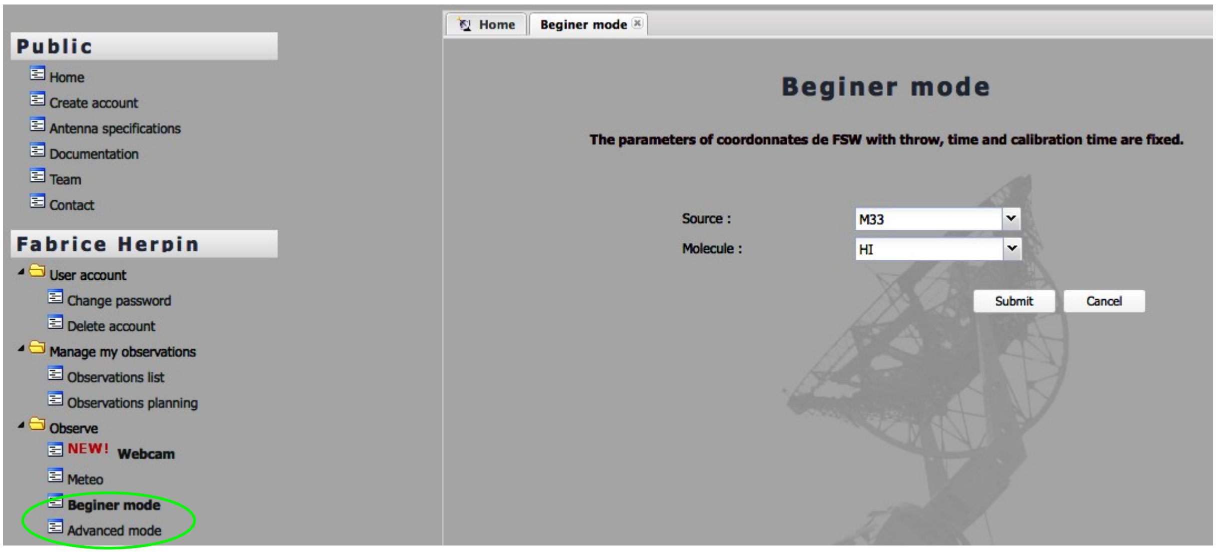


Obviously, you are not allowed to click other people’s reservations. Selecting the ‘Observation list’ tab in the ‘Manage my observations’ menu shows you all of your observations.

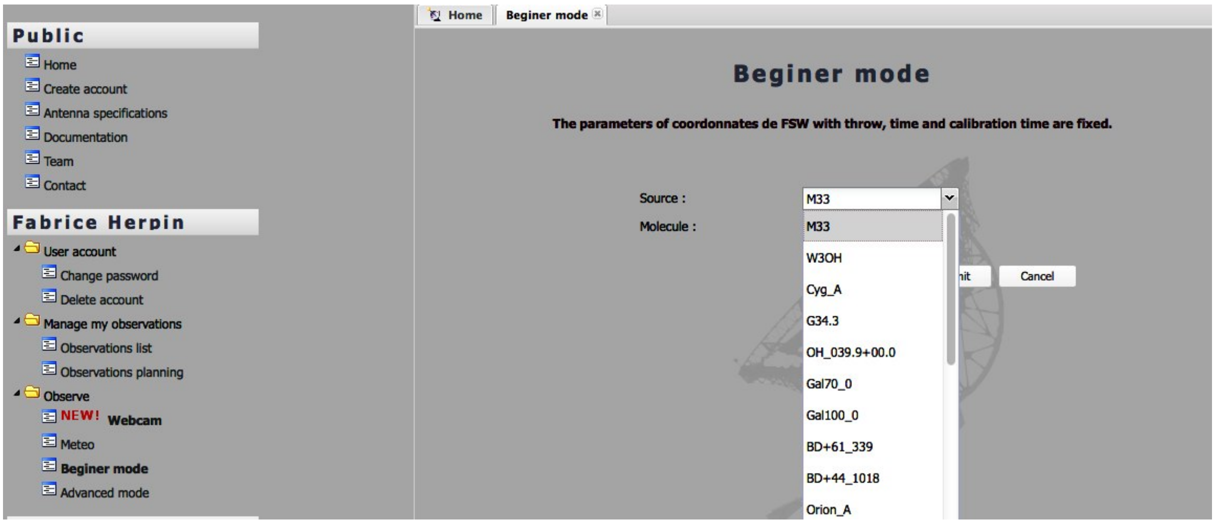


3. Observer en mode normal (i.e. novice) Normal (=beginner) mode observations

To start observing, simply click on 'Observe' in the menu on the left and choose either '*beginner*' or '*expert*' mode. In Beginner Mode, you choose only the target, from a pre-defined list, and the gas species that you will observe.

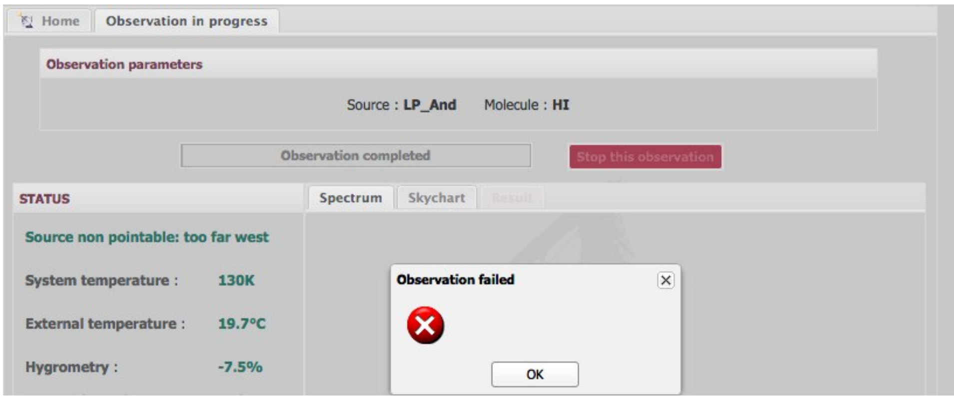


The gas species are atomic hydrogen, called **HI** ('H one'), at a radio frequency of 1420 MHz, and hydroxyl molecules, OH, near 1600 MHz. *The other telescope settings, such as integration time, are set.*

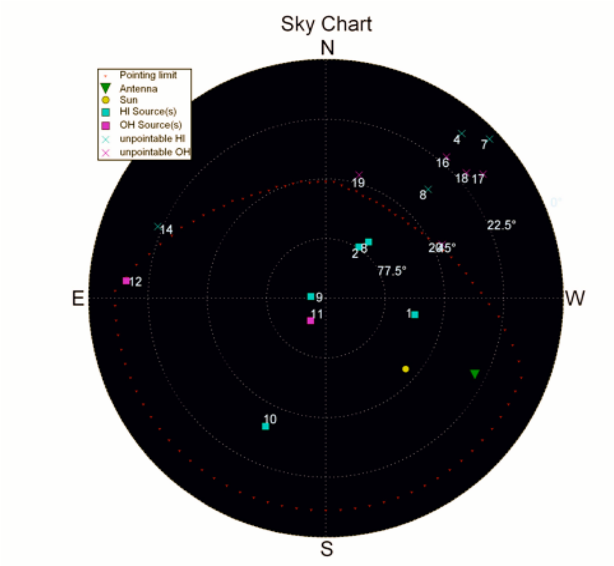


As an example, one can pick the galaxy M33. Clicking 'OK' starts the observation, that is, points the telescope in the right direction, and then acquires some data.

If the source is not currently in a part of the sky that the telescope can point to, a message appears, and you must pick a different target.



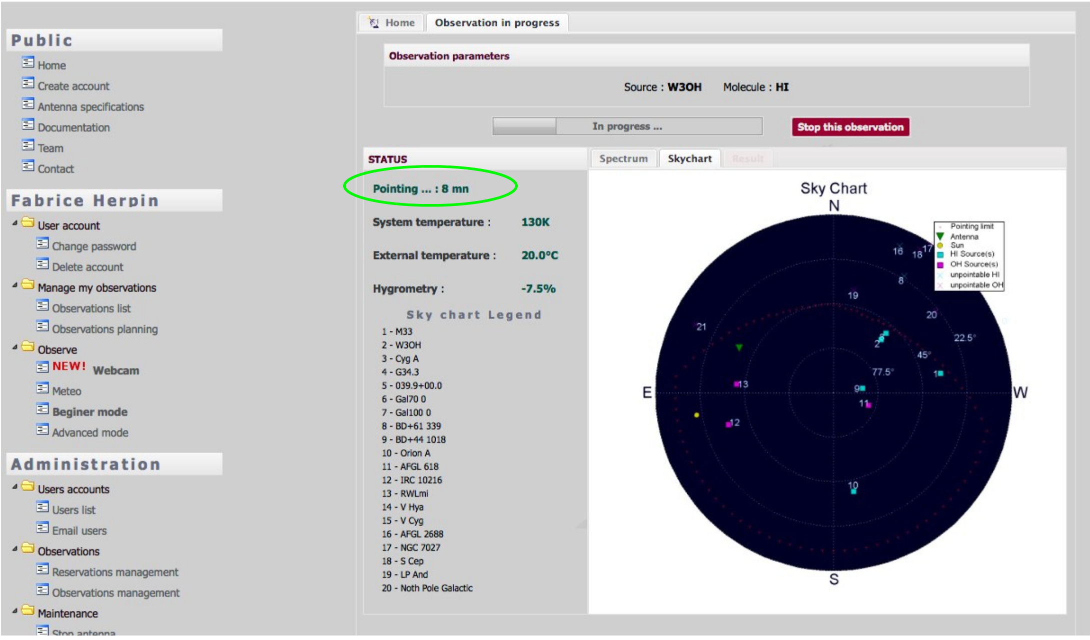
Use the sky chart to identify HI sources (blue squares) or OH sources (pink squares) that are within the faint, red dashed curve that indicates the sky zone accessible by the telescope. The green triangle shows where the telescope is currently pointing. The symbol numbers correspond to the objects list in the legend, namely



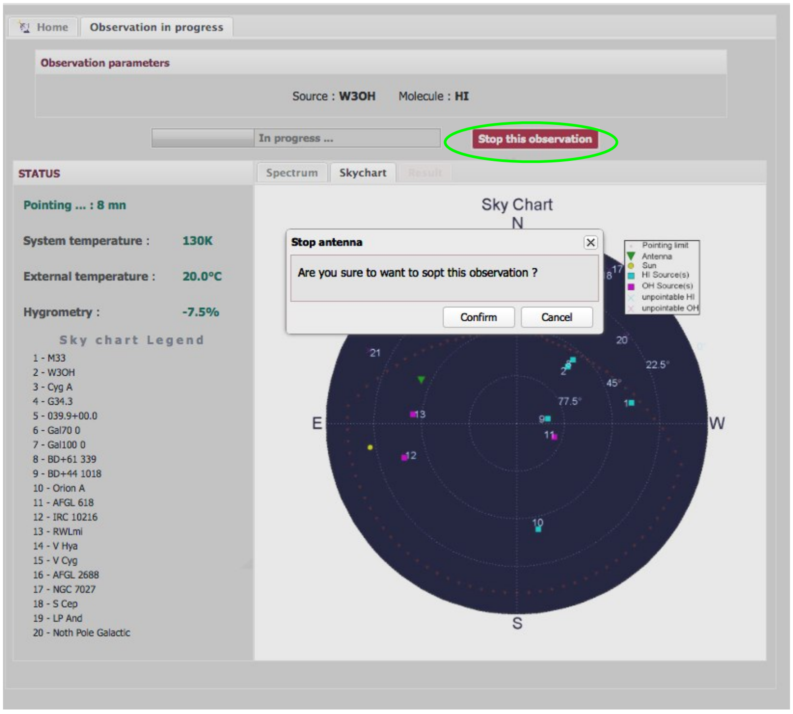
1- M33 (HI)
2- W3OH (HI)
3- Cyg A (HI)
4- G34.3 (HI)
5- OH 039.9+00.0 (HI)
6- GAL70.0+0.0 (HI)
7- GAL100.0+0.0 (HI)
8- BD+61.339 (HI)
9- BD+44.1018 (HI)
10- Orion A (HI)
11- AFGL618 (OH)
12- IRC+10216 (OH)
13- RW LMi (OH)
14- V Hya (OH)
15- V Cyg (OH)
16- AFGL2588 (OH)
17- NGC7027 (OH)
18- S Cep (OH)
19- LP And (OH)
20- North Galactic pole

You can also use ephemeris software to see where sources will be in the sky at various times. *XEphem* (http://www.clearskyinstitute.com/xephem/) runs on Mac and linux, whereas *Carte du ciel* (http://www.ap-i.net/skychart/fr/start) and Stellarium (http://www.stellarium.org/) run on all platforms.

Once you confirm your choice, the radio telescope will start moving towards the target source.

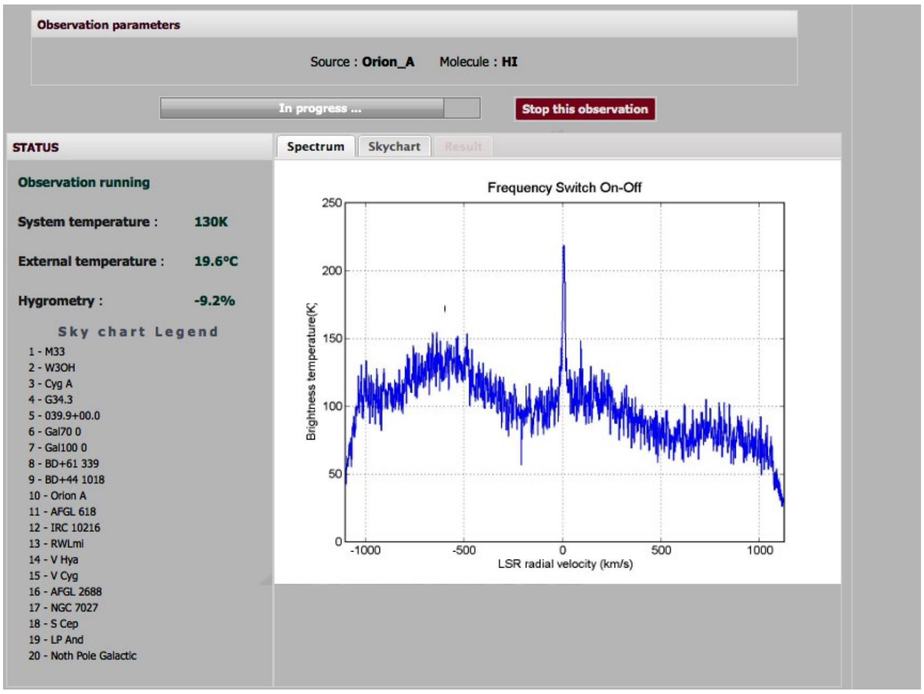


The time to reach the target depends on how far it is from where the telescope was initially pointed. In the example shown, it took 11 minutes. The maxium time is roughly 30 minutes. You can stop the telescope at any time by clicking on the red button.



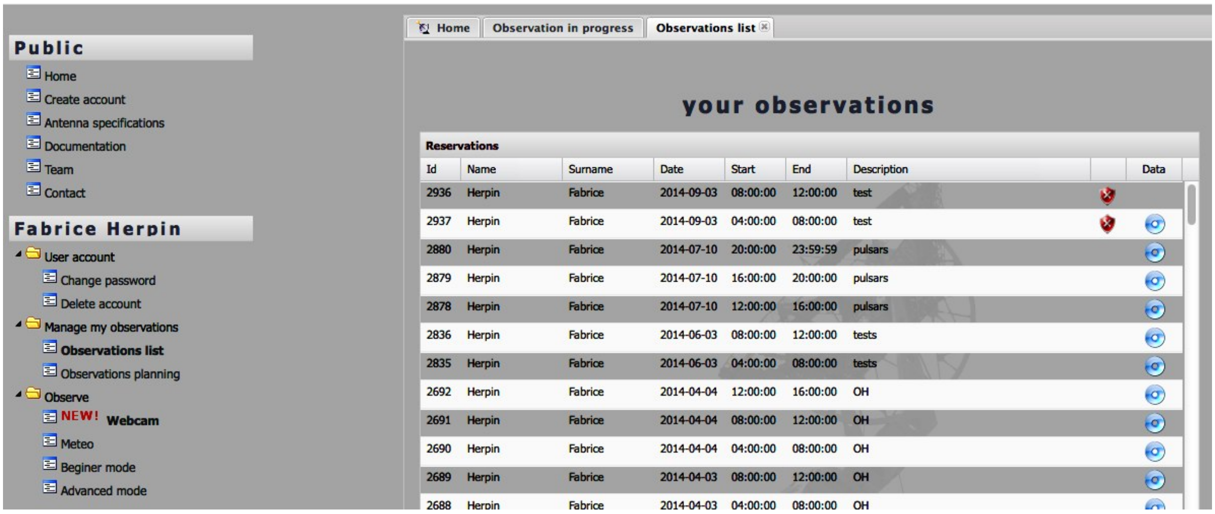
After reaching the target, the telescope automatically switches to tracking mode, moving slowly to compensate for the Earth's rotation. The telescope thus remains accurately oriented in spite of the apparent motion of the stars across the sky.

The observation then begins, lasting for **30 seconds** in beginner mode. The resulting plot of the spectrum is updated in real time, and appear on the "Spectrum" tab.



A message alerts you that the observation has ended.

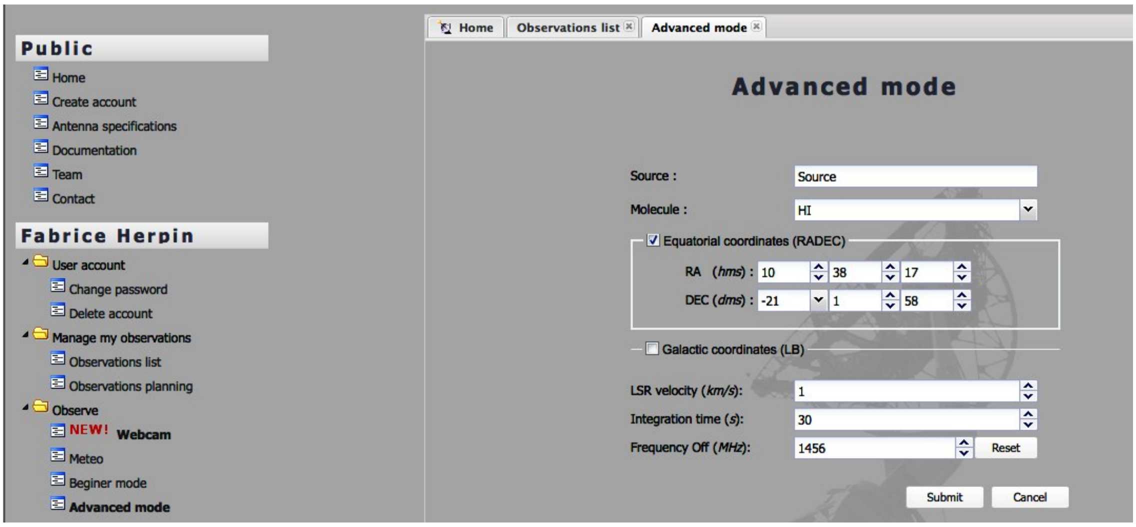
A screen capture allows you to keep a copy of your observation. You can also obtain a collection of files from your observation by clicking on the CD. The files include the spectral graph; text files where three columns correspond to the radio intensity as a function of radio frequency, or of the radial velocity of the source along the line of sight (this is explained further, below); and some files containing other information related to the data acquisition. The data can also be obtained by clicking on the CD in the "Your Observations" list, as shown



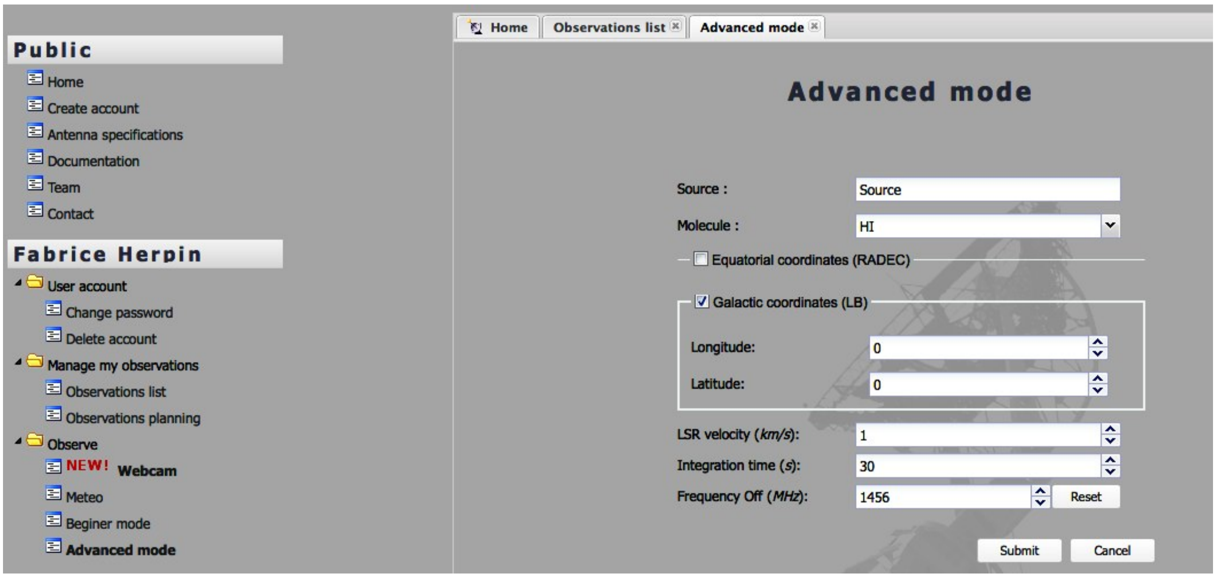
in the figure. The data is thus saved onto your own computer.

4. Observations in Expert Mode

When you choose Expert Mode, more parameters can be set than in Beginner's mode.



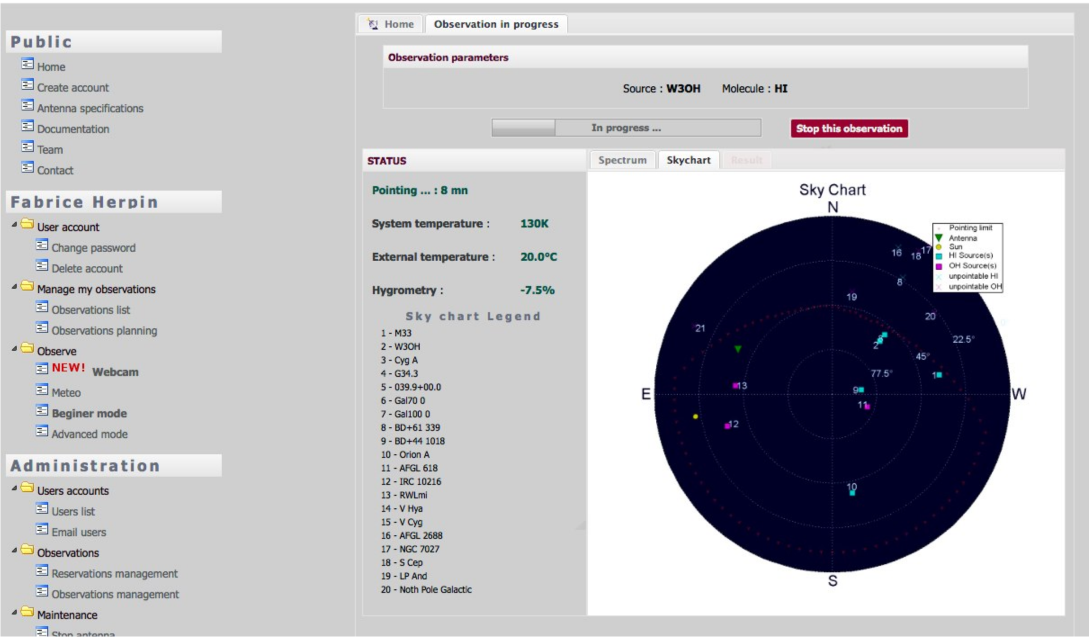
Instead of a pre-defined list of targets, you must now **indicate the object's celestial coordinates yourself**. You can choose between equatorial coordinates (right *ascension and declination*), or *Galactic longitude l and latitude b*. You should also indicate a name for your target.



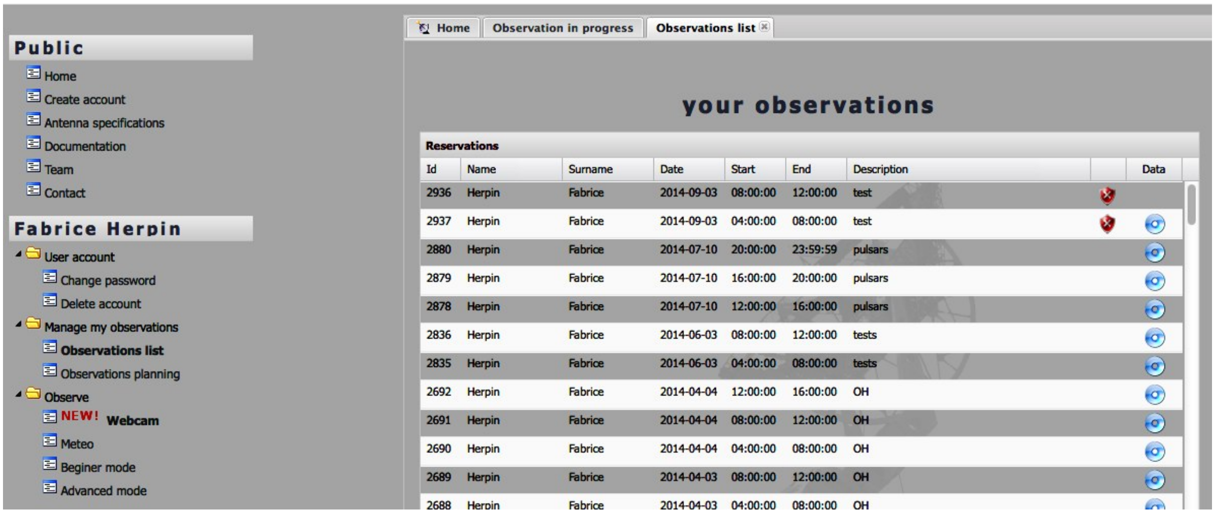
We suggest using names that will help identify the observation later, such as l_100_b_0 for an observation of the Galaxy at (l,b) = (100, 0) degrees. The name is used for the data files that will be produced.

You can specify the **target's radial speed** relative to the LSR = Local Standard of Reference (which is, roughly, the Sun). If you don't know it, simply use zero: your source's peak in the spectrum will not be centered, which is generally not a problem.

You then choose an **integration time**, that is, how long the observation will last. For most HI sources a few minutes are enough. Finally, *if needed*, you can change the OFF reference frequency. In most cases this is unnecessary and is not recommended. But if you suspect that the reference frequency is suffering from interference (noise from the local environment) you can try other frequencies, starting with the range 1450 to 1460 MHz. You then accept your parameters and to start the observation. The telescope time-to-pointing is indicated.



Once the data acquisition is complete and your spectrum and been displayed on the screen, you can screen capture, or click on the CD to obtain a .zip archive of your data files, as for Beginner Mode.



VI. *Mapping the Galaxy*

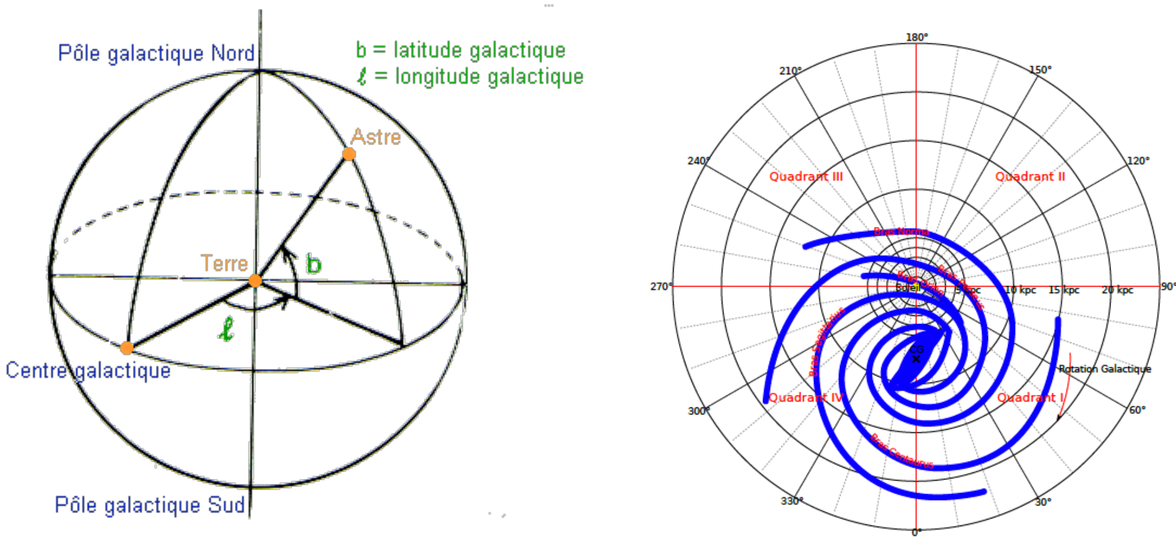


Figure 5: Left: Galactic coordinate system. Right: The b=0 plane of our galaxy, the Milky Way, showing longitude l and the spiral arms. The Sun and Earth are at the orgin.

1. Galactic coordinates

The Sun is roughly 8.5 kpc from the center of the Milky Way. Most of galaxy's stars and gas clouds lie in a thin disk rotating around the galactic center. The Sun's tangential **(Fabrice c'est écrit 'radiale' en V.F., c'est une coquille, non?)** velocity is about 220 km/s. Thus, it takes the Sun about 240 million years to make a complete tour.

Galactic coordinates (l,b) conveniently describe the position of a star or cloud, where *l is called galactic longitude* and *b is galactic latitude*. As shown in the figure, the reference system is centered on the Sun. Latitude b=0 corresponds to the Galactic plane (the Milky Way's disk). The galaxy is divided into four quadrants, shown in Figure 5:

- *I : 0° < l < 90°*
- *II : 90° < l < 180°*
- *III : 180° < l < 270°*
- *IV : 270° < l < 360°*

2. Hydrogen in the Galaxy

10 to 15% of the mass of our galaxy is gas, and most of the gas is atomic hydrogen. Collisions of an atom with other matter or light can 'excite' its electron to a higher energy state. When an atom 'relaxes', that is, its electron's spin flips to become anti-parallel with the proton's, attaining a lower energy state, the electron radiates at a precise frequency near 21 cm (1420 MHz). Relaxation takes about 10 million years to happen for a given atom. But the huge number of atoms in interstellar space makes the combined signal from all the relaxing atoms detectable. The spectra we measure with the Wurzburg antenna cover a frequency range above and below 1420 MHz: if the emitting gas is moving towards us, the frequency is shifted higher ('Doppler shift'). Similarly, if the gas is receding, the frequency is lower. Thus,

measuring the peak's position allows us to deduce the component of the gas's speed along the line of sight. By assuming that the gas is rotating along with the rest of the Milky Way, we can translate the radial velocity to a distance.

3. Geometry of the Galaxy

When pointing the radio telescope towards a given gas cloud within the Galaxy, we see not its total velocity V but only the radial component V_r along the line-of-sight. In Figure 6, SM is the line of sight. V_0 is the Sun's velocity, tangent to the circular movement of the Galaxy. V_r is the projection on V on SM, minus the projection of V_0 on SM (that is, the component of the Sun's motion along the line-of-sight).

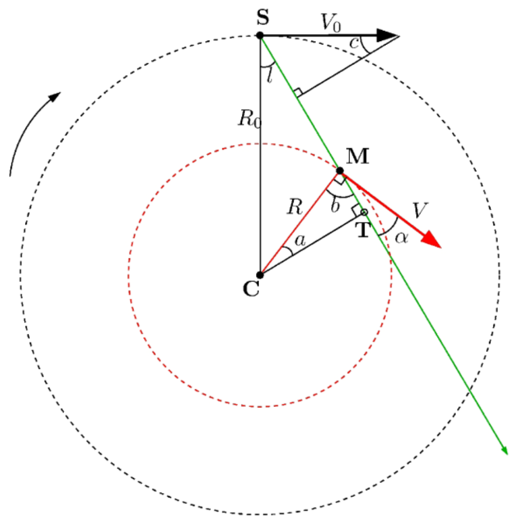


Figure 6: Galactic geometry. S is the Sun ("you are here"), C is the Galactic center, and M is the source being observed.

Summarizing:

V_0 = Sun's tangential velocity around the Galactic center (220 km/s)
R_0 = CS = distance from the Sun to the Galactic center (8.5 kpc)
l = Galactic longitude
V = Gas cloud's total velocity
R = CM = distance between the cloud and the Galactic center
r = MS = distance between the cloud and the Sun

We have:

$$V_r = V \,.\cos \alpha - V_0 \,.\sin c \qquad (1)$$

Inspection of Figure 6 shows:

$$(90 - l) + 90 + c = 180 \Rightarrow c = l \qquad (2)$$

So that we can re-write Eq. 1 as:

$$V_r = V \,.\cos \alpha - V_0 \,.\sin l \qquad (3)$$

Since the line CM is at a right angle to V, we have:

$$b = 90 - a = 90 - \alpha \;\Rightarrow a = \alpha \qquad (4)$$

The distance CT can be expressed in two ways:

$$CT = R_0 .\sin l = R .\cos \alpha \ \Rightarrow \cos \alpha = R_0/R . \sin l \tag{5}$$

Hence, V_r becomes:

$$V_r = (V . R_0/R - V_0) . \sin l \tag{6}$$

This equation has two unknowns, R and V. To obtain R, we assume from here on that V is a constant independent of R[2].

4. Galactic Rotation Curve

Several clouds can lie along a single line-of-sight. The cloud with the greatest radial velocity lies at the 'tangent point' T, where we see the velocity vector parallel to the line-of-sight. We then have

$$R = R_0 .\sin l \tag{7}$$

$$V = V_{r,max} + V_0 . \sin l \tag{8}$$

By measuring $V_{r,max}$ over a range of longitudes l we can calculate R and V for each measurement, to obtain an observed rotation curve $V(R)$ as in Figure 7.

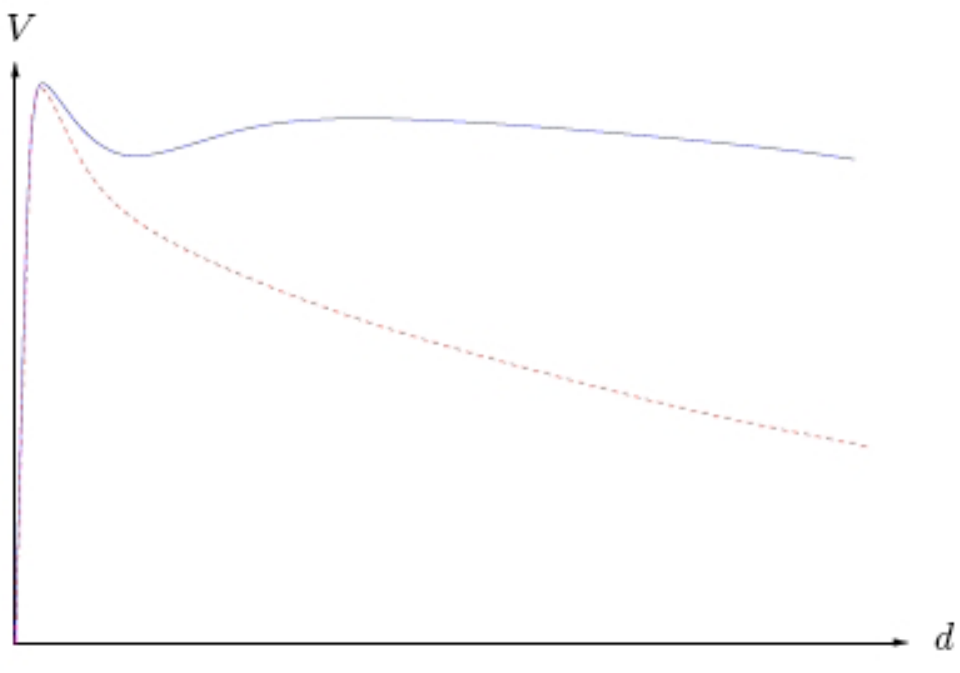


Figure 7: Observed Galactic rotation curve (solid blue), and the expected curve (red dashed) if the Galaxy's mass were only that of the visible stars.

[2] In the scientific jargon, V constant with R is called a « flat rotation curve ». The discovery in the 1920's that most galaxies have flat rotation curves was the first major step towards the discovery of the existence of Dark Matter.

5. Distance R between a cloud and the Galactic center.

To find the distance R to a given detected gas cloud we use all the radial speeds measured along that line-of-sight, and not just the maximum value as above. We substitute $V(R)=V_0$ in Eq. 6, that is, we approximate the blue solid curve in Figure 7 as being perfectly 'flat'. This gives

$$V_r = (R_0/R-1) . V_0 . \sin l \quad (9)$$

which we invert to obtain :

$$R = (V_0 . R_0 . \sin l) /(V_0 . \sin l + V_r) \quad (10)$$

6. The cloud's position in polar coordinates (r,l)

The simplest way to map the Galaxy and see the spiral arms is to express each cloud (each peak in the spectrum of radio intensity versus radial velocity) in polar coordinates (r,l). As before, r is the distance between the Sun and the cloud, and l is the cloud's longitude. galactique. From Figure 6:

$$R^2 = R_0^2 + r^2 -2 . R_0 . r . \cos l \quad (11)$$

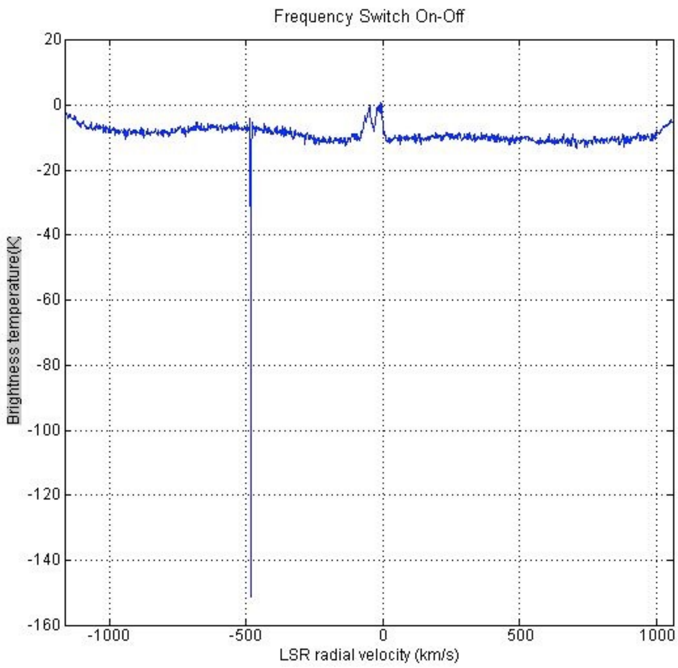
This quadratic equation has two solutions:

$$r\pm = \pm \sqrt{(R^2 - R_0^2 . \sin^2 l)} +R_0 . \cos l \quad (12)$$

In quadrants II and III, only one solution is physical (r positive), and the position of the emitting cloud is uniquely determined. For quadrants I and IV, two solutions are possible, corresponding to the two intersections of the line-of-sight MS with the 'solar circle' (red dashed in Figure 6).

VII. *Data Analysis*

1. Using the spectral plot



The image file obtained from the observation is a *spectrum*, the intensity of the signal picked up by the antenna for the molecule chosen by the user (HI in this example), as a function of the radial velocity V_r. Recall that we obtain V_r for a given measured radio frequency by assuming that the signal occurred at the HI relaxation frequency (1420 MHz), but that the frequency was Doppler shifted due to the movement of the emitter relative to the Earth. (More precisely, not the Earth, but a point near the Sun that takes into account the sun's movement relative to the general Galactic motion, called the Local Standard of Rest[3], or LSR.) In the spectral figure, a peak appears near -20 km/s. This is interpretated as an HI emitter with that velocity component along the lin-of-sight to the LSR.

The y-axis of the spectral plot is the *signal power* expressed as a *brightness temperature* in Kelvins (degrees above absolute zero). A bigger peak indicates a larger number of hydrogen atoms.

The overall signal shape away from the double HI peaks is called the *baseline*. It is a combination of the total radio emission from various types of gas along that line-of-sight, the emission of the Earth's atmosphere at these radio frequencies, and of the radio telescope itself and its electronics. For our purposes, we can consider the baseline to indicate the noise level. **(Fabrice on dit qq chose à propos du gros spike negative à -490 km/s? Pour la version anglaise je propose de remplacer par un truc plus clean, non?)**

2. Using the (X,Y,Z) text file

[3] http://en.wikipedia.org/wiki/Local_standard_of_rest

For each of your observations, for each second of observations, a file called «data_sourcename_date_hour_x.class» is generated, containing

- une 1ère colonne avec l'intensité du signal (axe des *Y* sur la précédente image)
- une 2ème colonne avec les vitesses (axe des *X* sur la précédente image)
- une 3ème colonne avec les fréquences (équivalent de la 2ème colonne par effet Doppler)
- 1st column: signal intensity Tb (y-axis of the spectrum)
- 2nd column: radial velocity V_r, in km/s (x-axis of the spectrum)
- 3rd column: radio frequency, in MHz (before Doppler calculation yielding V_r.

Any plotting software, such as Excel or gnuplot, allows you to reproduce the spectral plot.

3. Using CLASS

Here we explain how to improve the data analysis using professional software called CLASS, part of the GILDAS package, downloadable from http://www.iram.fr/IRAMFR/GILDAS . CLASS runs in a unix-like line command environment (linux, or mac).

Consider the contents of the directory where you have stored your data. A 60 second observation yields 60 files that integrate 1 second each. The source shown is called «74_00», observed 9 March 2011 beginning at 10:32 and 31 seconds. A screen shot of the directory contents is shown, and contains:

```
74_00_20110309_10h32mn31s.class          data_74_00_20110309_10h32mn31s_28.class data_74_00_20110309_10h32mn31s_47.class
data_74_00_20110309_10h32mn31s_1.class   data_74_00_20110309_10h32mn31s_29.class data_74_00_20110309_10h32mn31s_48.class
data_74_00_20110309_10h32mn31s_10.class  data_74_00_20110309_10h32mn31s_3.class  data_74_00_20110309_10h32mn31s_49.class
data_74_00_20110309_10h32mn31s_11.class  data_74_00_20110309_10h32mn31s_30.class data_74_00_20110309_10h32mn31s_5.class
data_74_00_20110309_10h32mn31s_12.class  data_74_00_20110309_10h32mn31s_31.class data_74_00_20110309_10h32mn31s_50.class
data_74_00_20110309_10h32mn31s_13.class  data_74_00_20110309_10h32mn31s_32.class data_74_00_20110309_10h32mn31s_51.class
data_74_00_20110309_10h32mn31s_14.class  data_74_00_20110309_10h32mn31s_33.class data_74_00_20110309_10h32mn31s_52.class
data_74_00_20110309_10h32mn31s_15.class  data_74_00_20110309_10h32mn31s_34.class data_74_00_20110309_10h32mn31s_53.class
data_74_00_20110309_10h32mn31s_16.class  data_74_00_20110309_10h32mn31s_35.class data_74_00_20110309_10h32mn31s_54.class
data_74_00_20110309_10h32mn31s_17.class  data_74_00_20110309_10h32mn31s_36.class data_74_00_20110309_10h32mn31s_55.class
data_74_00_20110309_10h32mn31s_18.class  data_74_00_20110309_10h32mn31s_37.class data_74_00_20110309_10h32mn31s_56.class
data_74_00_20110309_10h32mn31s_19.class  data_74_00_20110309_10h32mn31s_38.class data_74_00_20110309_10h32mn31s_57.class
data_74_00_20110309_10h32mn31s_2.class   data_74_00_20110309_10h32mn31s_39.class data_74_00_20110309_10h32mn31s_58.class
data_74_00_20110309_10h32mn31s_20.class  data_74_00_20110309_10h32mn31s_4.class  data_74_00_20110309_10h32mn31s_59.class
data_74_00_20110309_10h32mn31s_21.class  data_74_00_20110309_10h32mn31s_40.class data_74_00_20110309_10h32mn31s_6.class
data_74_00_20110309_10h32mn31s_22.class  data_74_00_20110309_10h32mn31s_41.class data_74_00_20110309_10h32mn31s_60.class
data_74_00_20110309_10h32mn31s_23.class  data_74_00_20110309_10h32mn31s_42.class data_74_00_20110309_10h32mn31s_7.class
data_74_00_20110309_10h32mn31s_24.class  data_74_00_20110309_10h32mn31s_43.class data_74_00_20110309_10h32mn31s_8.class
data_74_00_20110309_10h32mn31s_25.class  data_74_00_20110309_10h32mn31s_44.class data_74_00_20110309_10h32mn31s_9.class
data_74_00_20110309_10h32mn31s_26.class  data_74_00_20110309_10h32mn31s_45.class new.30m
data_74_00_20110309_10h32mn31s_27.class  data_74_00_20110309_10h32mn31s_46.class
```

- Sixty (i = 1 to 60) files called «data_sourcename_date_hour_i.class» of one second observations in (X,Y,Z) text format,
- a file «sourcename_date_hour.class» which is a short CLASS script to convert your files from text to CLASS format,
- The CLASS initialization file «new.class» called by the above script.

Type CLASS at the command line (presuming you have installed it and that your paths are well defined) from the directory containing your data. Run the script «sourcename_date_hour.class» by typing the command shown, that is, *@ script_file_name* followed by *enter*.

```
LAS90> @74_00_20110309_10h32mn31s
```

When the script has finished executing, a new file called «sourcename_date_hour.wurz» will have been created (here, «74_00_20110309_10h32mn31s60.wurz»), containing your data in the CLASS format.

To read the file, type
file in sourcename_date_hour.wurz then *find*

```
LAS90> file in 74_00_20110309_10h32mn31s60.wurz
I-CONVERT,  File is  [Native]
I-INPUT,  74_00_20110309_10h32mn31s60.wurz successfully opened
LAS90> find
I-FIND,         60 observations found
LAS90>
```

and *lis*
Your sixty observations are listed on the screen.

```
LAS90> lis
Current index contains:
      1; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
      2; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
      3; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
      4; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
      5; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
      6; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
      7; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
      8; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
      9; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     10; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     11; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     12; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     13; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     14; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     15; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     16; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     17; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     18; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     19; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     20; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     21; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     22; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     23; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     24; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     25; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     26; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     27; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     28; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     29; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     30; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     31; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     32; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     33; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     34; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     35; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     36; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     37; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     38; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     39; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     40; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     41; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     42; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     43; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     44; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     45; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     46; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     47; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     48; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     49; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     50; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     51; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     52; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     53; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     54; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     55; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     56; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     57; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     58; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     59; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
     60; 9 74_00      HI        WURZBURG      +0.0     +0.0 Eq    79.  1
LAS90>
```

The number at far left is an index of your '74_00' observations, taken at the HI frequency, with the «WURZBURG» telescope.
To improve the signal-to-noise ratio, we add all the observations together, using the *average* command.

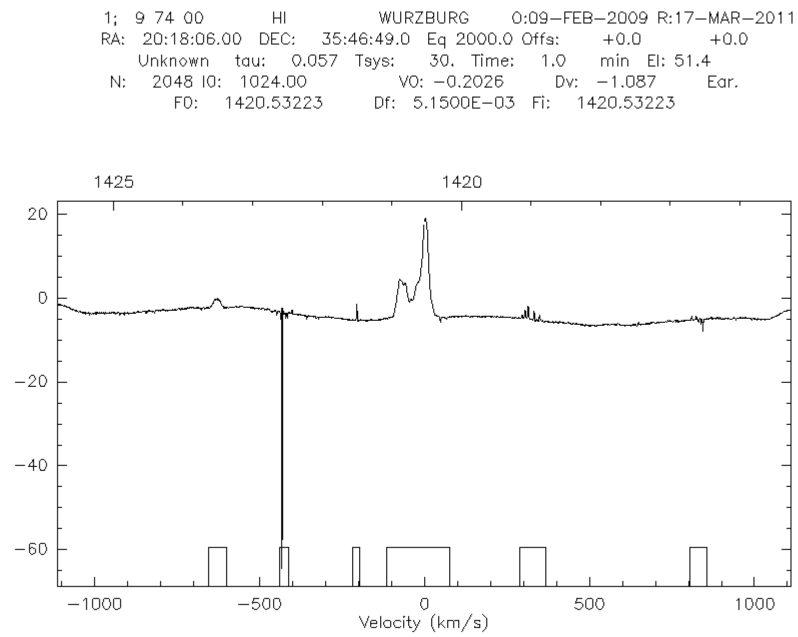
```
LAS90> average
```

The command *plot* posts the data to the screen.

Typing *SET FORMAT LONG* followed by *PLOT* adds additional information to the plot, giving this:

```
LAS90> pl
LAS90> set format long
LAS90> pl
LAS90>
```

The figure header lists the source name, the gas species (HI or CO), the telescope name, observation date, the pointing coordinates in Right Ascension and Declination, the total integration time used in the plot (1 minute, in this case), the source speed that you may have entered (here, -0.2 km/s), and so forth.



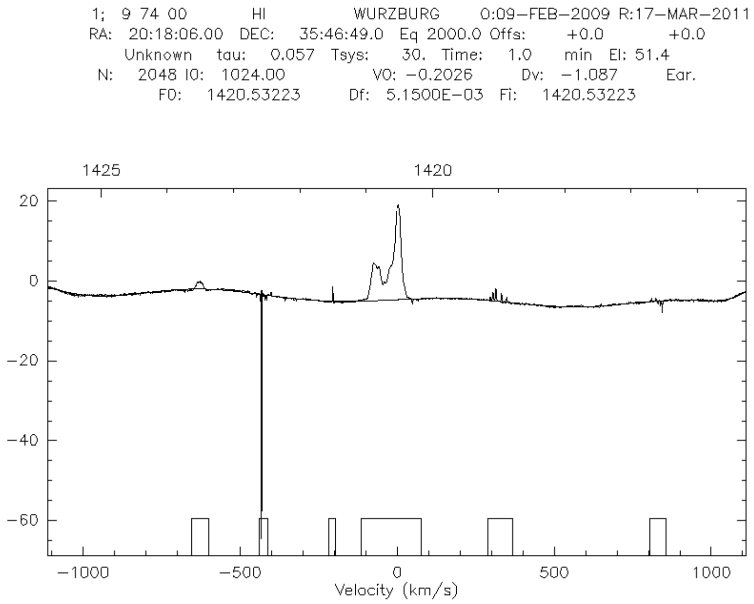
Next, we clean the signal by removing the base line. To define the velocity interval containing the signal region that we wish to explore, type
SET CURSOR ON
SET WIN
You can now use your mouse to move the cursor over the plot image. Press the 'space' bar once when the cursor is to the left of the signal region ; and again on the right, and then type 'E' to exit the interactive mode. Typing
DRAW WIN
then redraws the window, for the selected region.

```
LAS90> set cursor on
LAS90> set win
LAS90> draw win
LAS90>
```

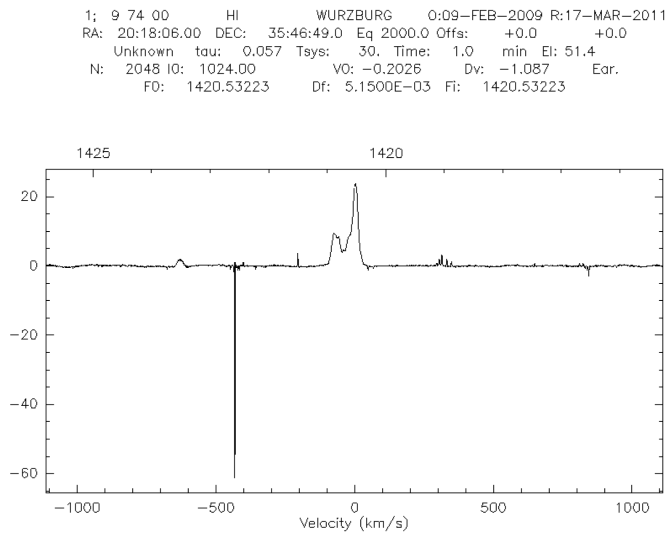
To model the baseline, excluding the signal region, use the command
BASE 9 /PL

```
LAS90> base 9 /pl
I-POLYNO,  Degree  2 would be even better
I-POLYNO,  degree:   9 rms: 0.191     area:  995.     v0:  14.27     width: 0.000
LAS90> 
```

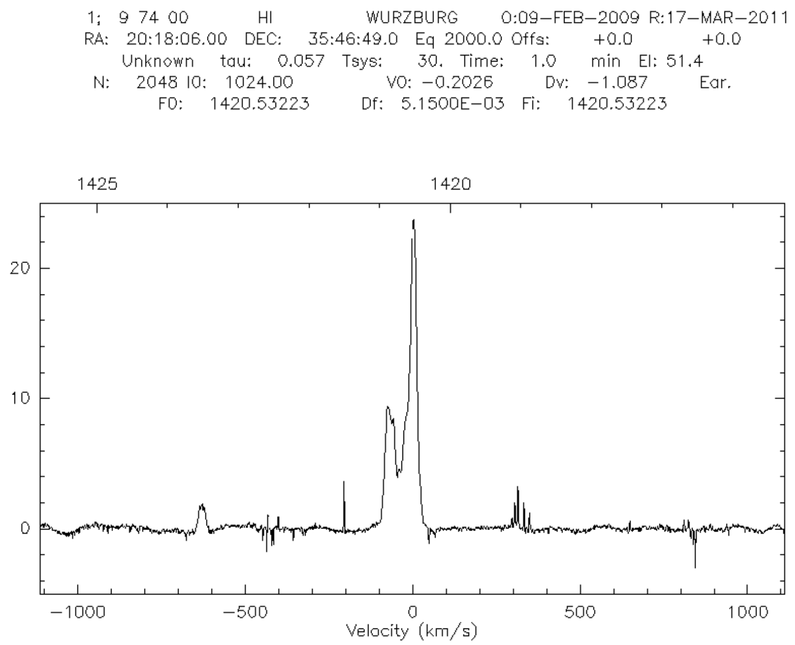
This determines a 9th order polynomial resembling the wavy baseline, in particular, to allow an interpolation across the signal region. You can iterate as many times as you please on the definition of the signal region and/or on the order of your polynomial, until the curve seems to match the data reasonably.
The *PLOT*command then displays the cleaned signal, after baseline subtraction.



To remove a noise spike, such as shown to the left of the signal, again type
DRAW
and use the mouse to place the cursor on the spike, then type
KILL



as many times as needed. Again, typing 'E' exits the interactive mode.
Then, when you next execute the *PLOT* command, you obtain the last spectrum shown below.



To save the result as an output file called, for example, CleanedSpectrum.Wurz, first type
FILE OUT CleanedSpectrum.Wurz m
followed by
WRITE

To re-display the file with CLASS, the command sequence is
FILE IN CleanedSpectrum.Wurz
FIND
LIS
GET FIRST
PLOT

Alternatively, you can save the plot as a postscript file,
HARD CleanedSpectrum.eps/DEV EPS FAST

VIII. *WÜRZBURG TEAM*

The Würzburg project is a team effort. Key contributors include

- *Organisation & coordination*: F. Herpin and H. Soulié, with lots of help from P. Caïs, and in particular from A. Capéran for the financial dealings.
- *Mechanical* : J.C. Bouquier, F. Glize, M. Soulette, A. Triffaux, P. Truchelut
- *Electronics* : W. D'Anna , B. Quertier, P. Caïs, P. Camino, J.M. Desbats, S. Gauffre, Z. Salim
- *Programming* : S. Lopez , N. Autin, A. Caillo, W. D'Anna, B. Quertier, S. Rousseau.

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Finally, we thank P. Charlot, director of the LAB, and F. Grousset and E. Villenave, former director and director, respectively, of the OASU. The following institutions provided financial support : LAB, OASU, Université de Bordeaux, Ecole doctorale de Physique de Bordeaux, SF2A et Sciences à l'école.